NATIONAL ENERGY TECHNOLOGY LABORATORY

Low Rank Coal for IGCC:
Conventional & Advanced Technologies

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Presentation Overview

- Why low rank coal?
- State-of-the-Art IGCC for low rank coal, cost and performance
- 2nd Gen IGCC for low rank coal, cost and performance
- Next steps for low rank coal IGCC pathway

Low Rank Coal Program Pathway

Why Low Rank Coal?

- **Low rank coals present unique challenges and opportunities for gasification and IGCC**
  - High inherent moisture, high in alkali metals (Na, K, Ca), high oxygen content, high reactivity, low sulfur, low cost
- **Gasification industry interviews show interest in low rank coal**
- **About half of world coal reserves are low rank -- a global market opportunity for advanced IGCC technology**

Cost and Performance Baseline for Fossil Energy Plants

Volume 3: Low Rank Coal and Natural Gas to Electricity

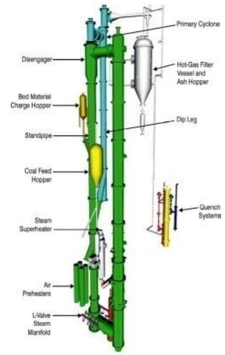
May 2011

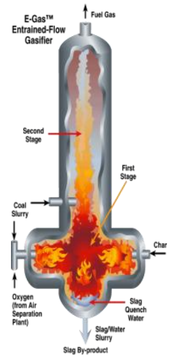
STATE-OF-THE-ART IGCC TECHNOLOGIES

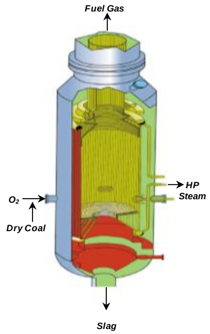
“Baseline Study” Project Objectives

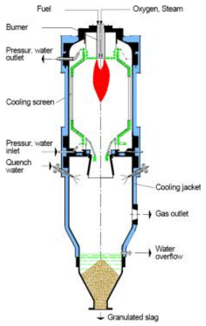
- **Primary Goal**
  - Comprehensive assessment of cost and performance of state-of-the-art fossil fuel power plants
    - Utilizing low-rank coals at western U.S. ambient conditions
    - With and without carbon capture and storage (CCS)
- **Project Objectives**
  - Complete cost and performance estimates for fossil-based electric generating technologies with and without CCS
    - Oxygen-blown IGCC, PC and CFBC and NGCC
  - Create baseline for state-of-the-art such that benefits of advanced technologies can be quantified
- **Approach**
  - Detailed Aspen models, consistent modeling and costing approach
  - Gasification vendor review for performance and cost results

IGCC Cases: Technical Design Basis







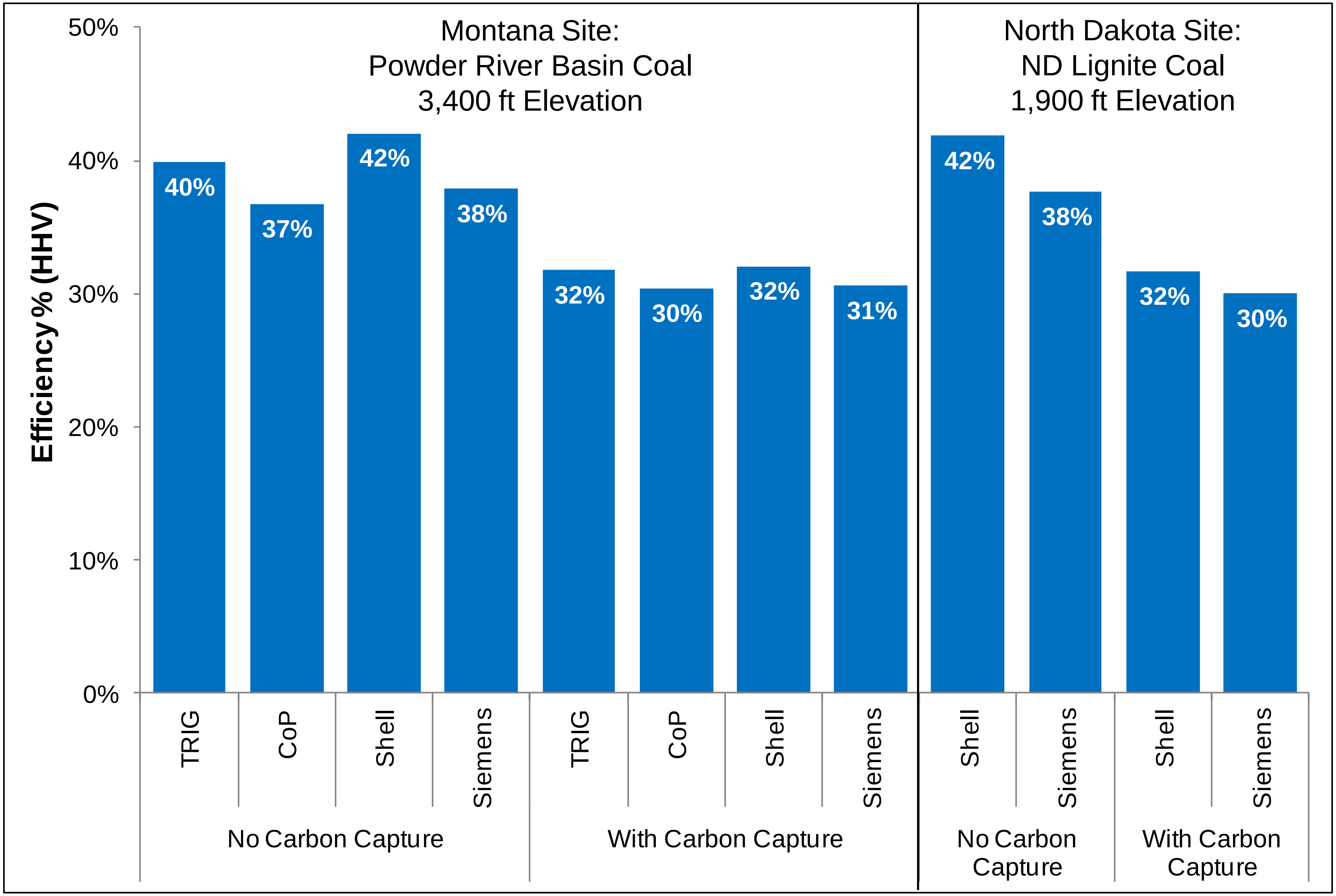


	Sounthern Company TRIG	ConocoPhillips E-Gas	Shell SCGP	Siemens (GSP/Noell)
Gasifier	Transport	Slurry; entrained	Dry-fed entrained	
Coal Type	PRB		PRB & ND Lignite	
Location/Elevation	Montana/3400 ft		PRB: Montana/3400 ft Lignite: ND/1900 ft	
Coal Drying	Indirectly heated fluidized bed	NA	WTA process	
Oxidant	Oxygen			
AGR for CO2 capture plants	2-Stage Selexol			
Gas Turbine	Advanced F-class (Nitrogen dilution and air integration maximized)			
Steam Cycle (psig/F/F)	1800/1050/1050 (non-CO_2 capture cases) 1800/1000/1000 (CO_2 capture cases)			
Carbon Capture	83%	90%		
Availability	80%			

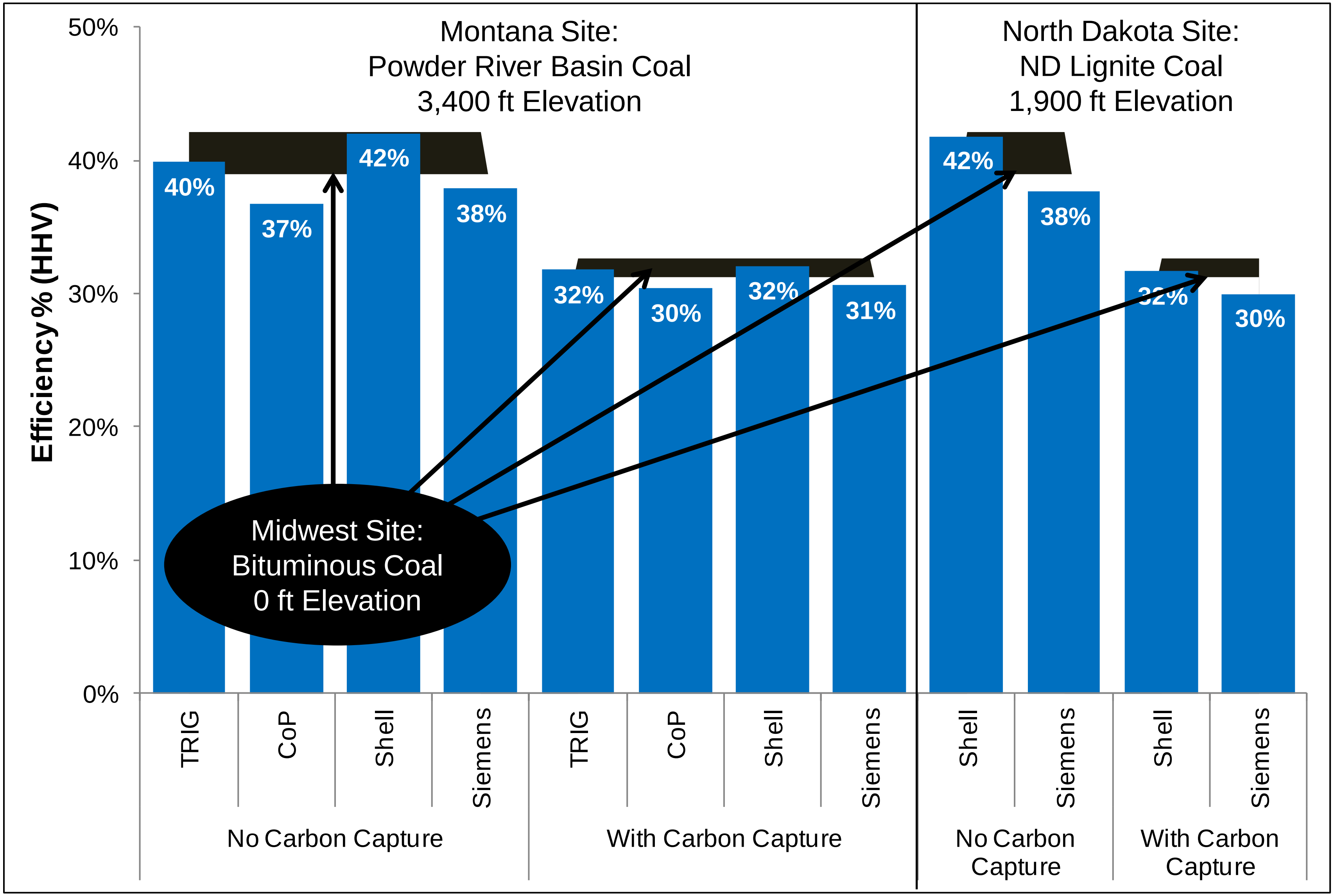
IGCC Cases: Economic Design Basis

Variable / Factor	Assumptions / Approach
Year Dollars	June 2007 (equivalent to January 2010 dollars based on Chemical Engineering Plant Cost Index)
Coal Price	PRB = \$0.89/MMBtu; ND Lignite = \$0.83/MMBtu
Capital Cost Basis	WorleyParsons and other vendor estimates; “Next-of-a-kind” application, contingencies assigned as appropriate; EPCM contracting strategy; owner’s costs included; +30/-15% accuracy
Capacity Factor	Equal to availability at 80%
Construction Period	5 years
Operational/Economic Recovery Period	30 years
Cost of Electricity Basis	Required sales price to meet 12% ROE; Reported in June 2007 dollars; Assumes a 3% escalation per year consistent with the assumed inflation rate
Capital Charge Factor	12.4%
CO2 Transport, Storage and Monitoring Costs	Costs added to COE; based on 50-mile pipeline transport to favorable saline aquifer formation

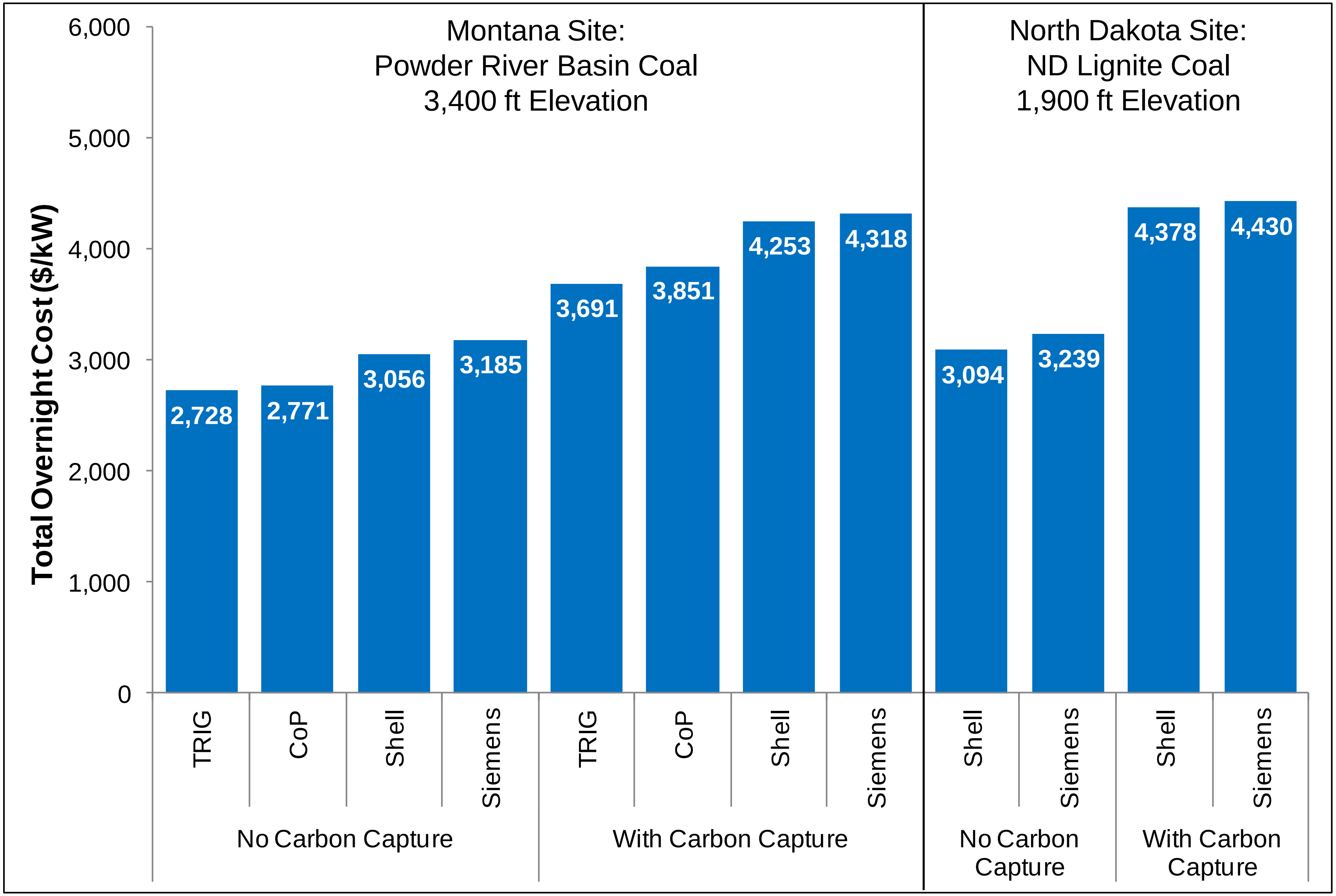
Conventional IGCC: Efficiency



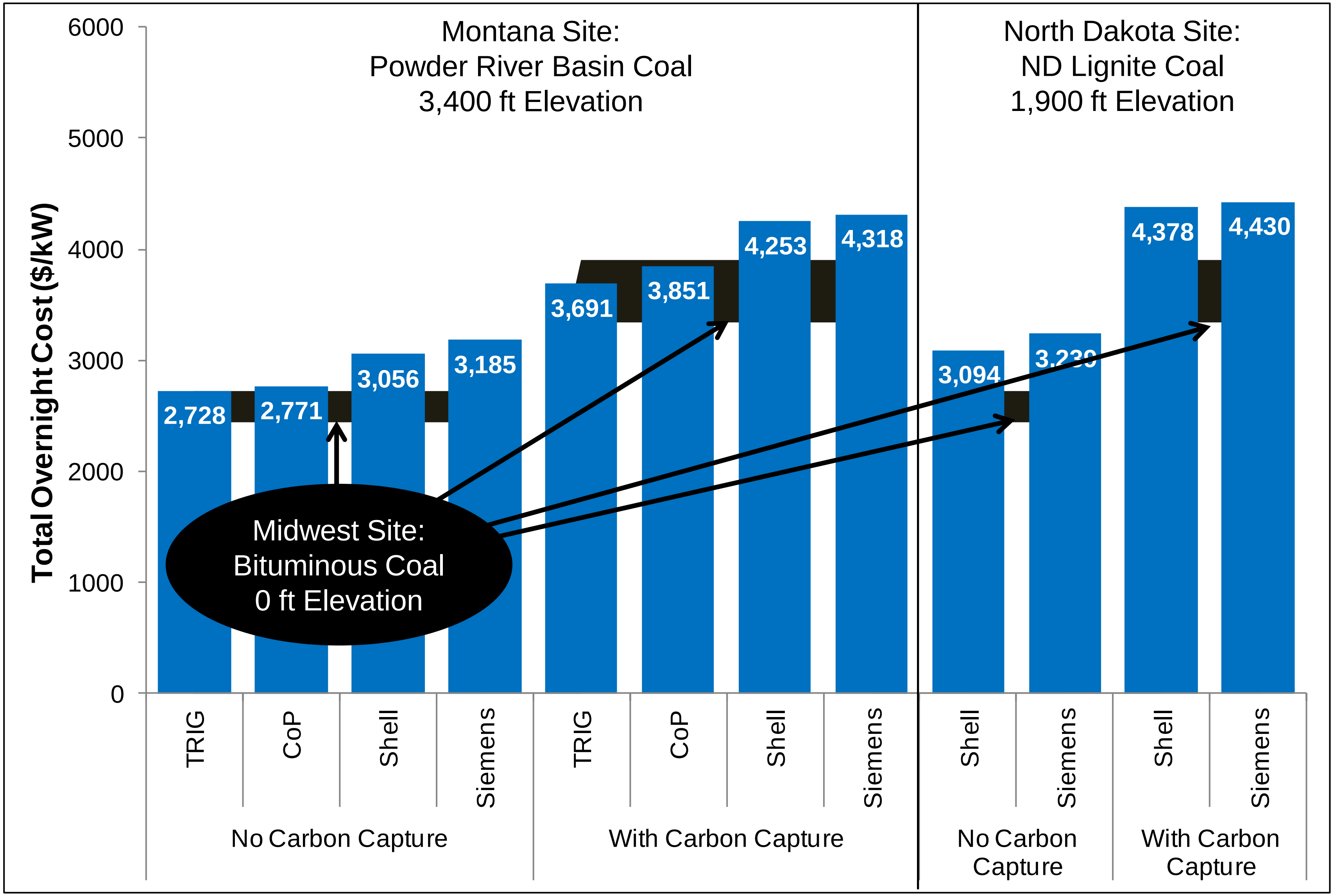
IGCC Efficiency: Bituminous Coal Comparison



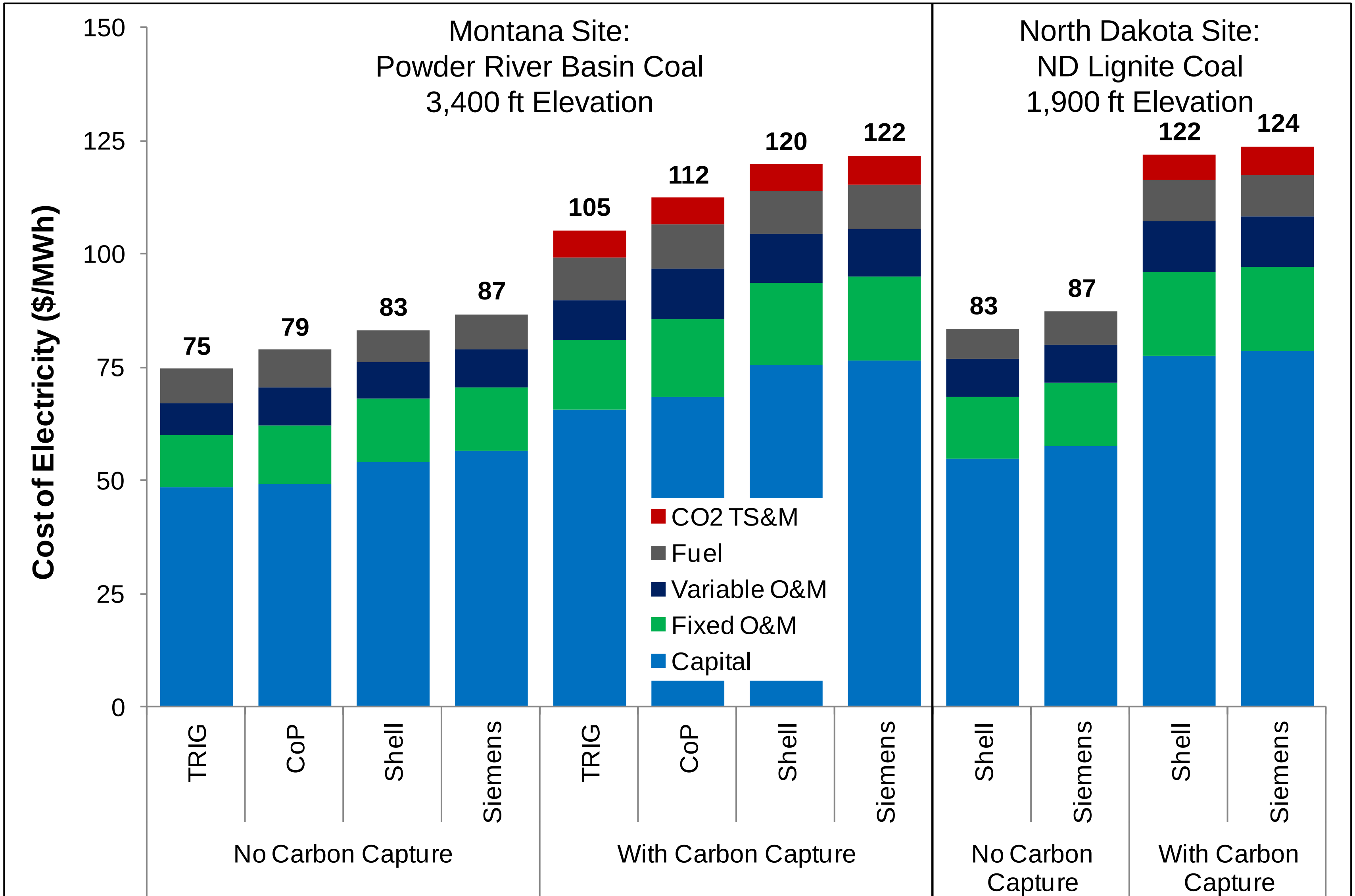
Conventional IGCC: Plant Cost



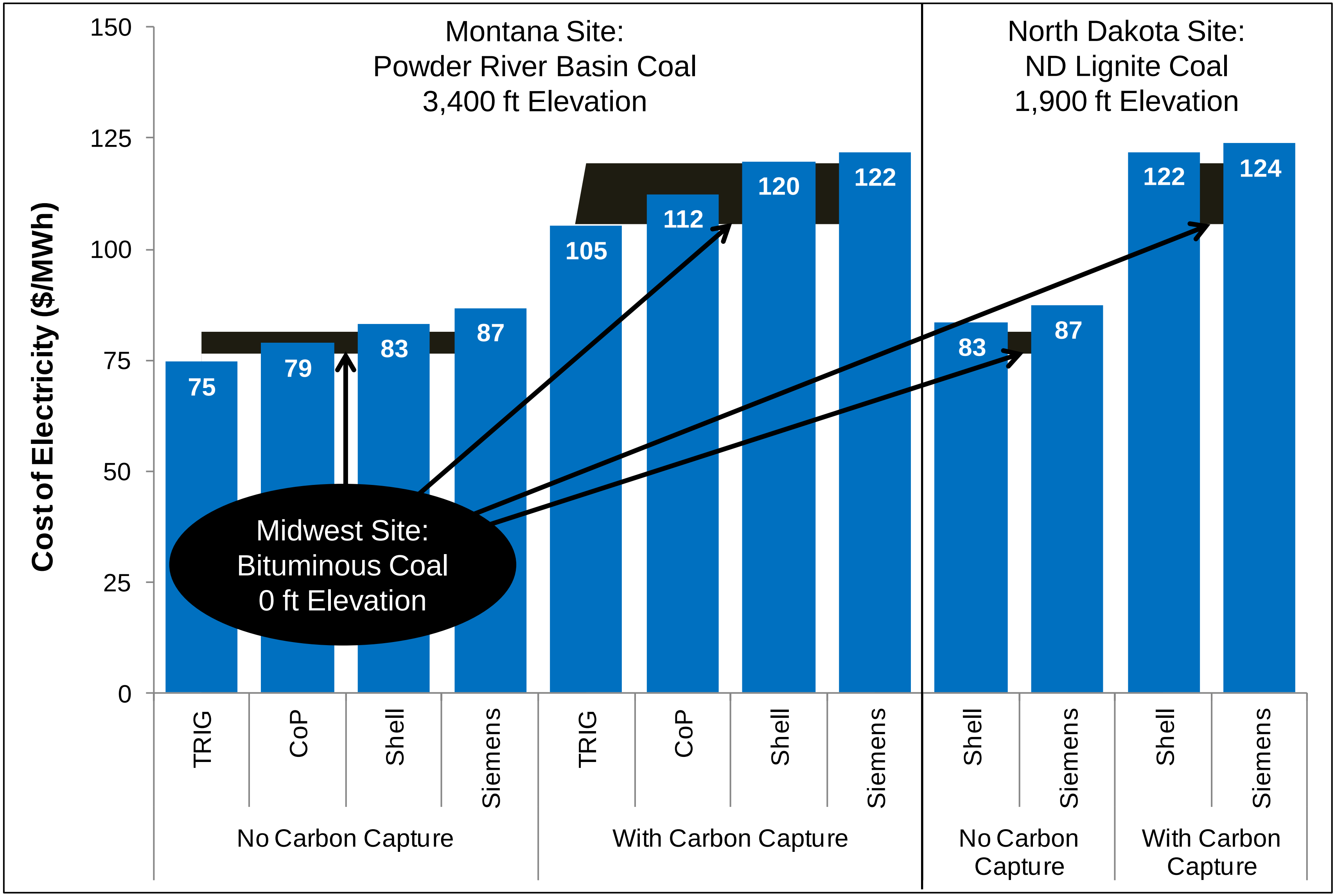
IGCC Plant Cost: Bituminous Coal Comparison



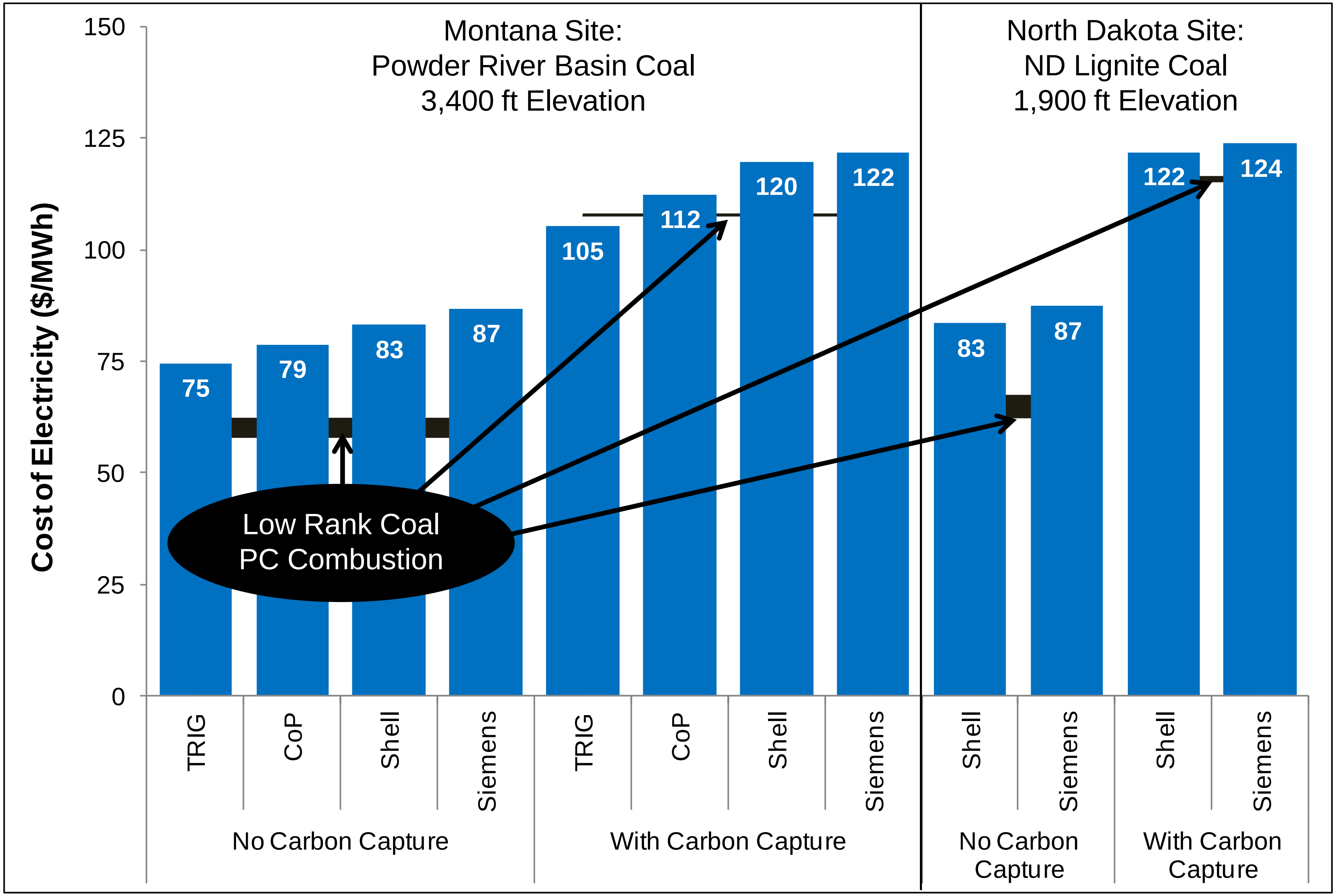
Conventional IGCC: COE



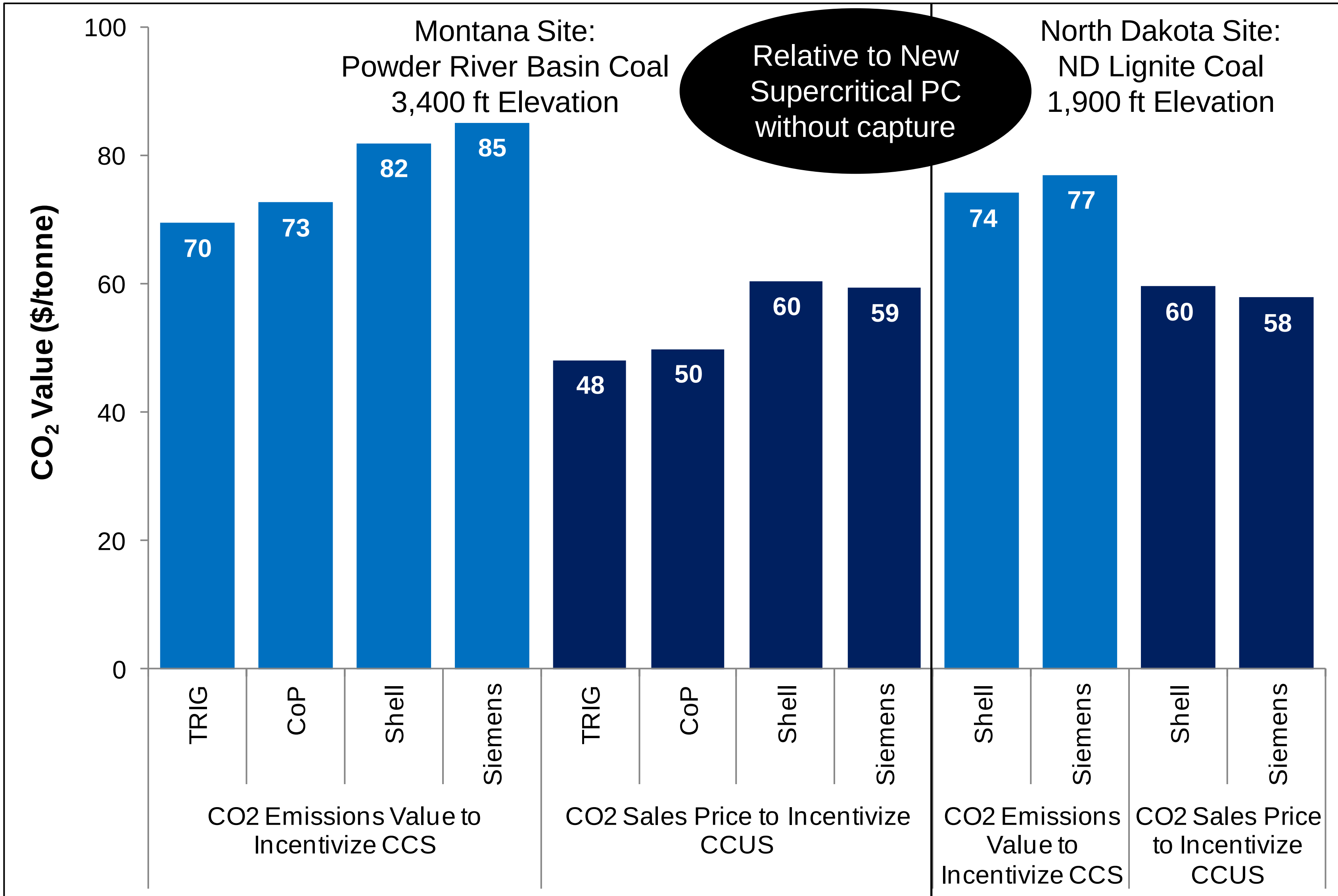
IGCC COE: Bituminous Coal Comparison



IGCC COE: Comparison to PC Plants



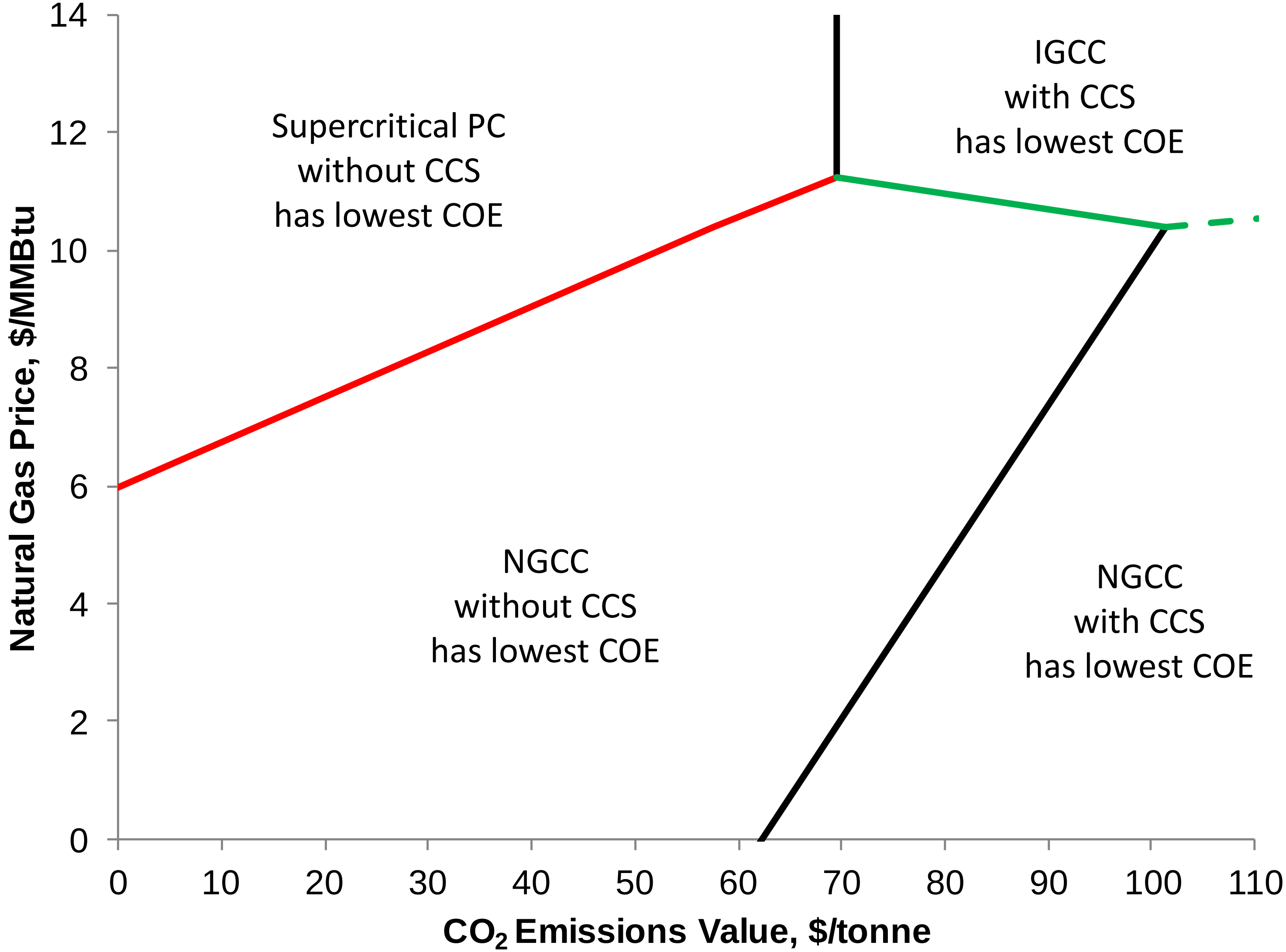
Conventional IGCC: CO_2 Capture Cost



CCUS = Carbon capture, utilization and storage

Lowest Cost Power Generation Options

Western (3400 ft): Today's NGCC versus Today's Coal (PRB)



Assumes capacity factor = availability (i.e. all plants including NGCC are base load).

Key Findings & Next Steps

- **Transport gasifier provides low cost IGCC power**
- **Slurry-fed gasification still competitive for high-moisture PRB coal**
- **Western location/low rank coal gasification COE on par with midwest/bituminous coal gasification**
- **IGCC with carbon capture COE essentially equivalent to PC PRB**
- **All coal systems, with and without carbon capture, face challenges competing in today's U.S. market**
  - No carbon policy
  - Current natural gas prices
- **Opportunities for IGCC**
  - State-of-the-Art: Co-production, CO_2 utilization via enhanced oil recovery
  - 2nd Gen: R&D and demonstration for advanced technologies

Current and Future Technologies for IGCC

Volume 3: An R&D Pathway Study for IGCC with Carbon Capture Using Low Rank Coal

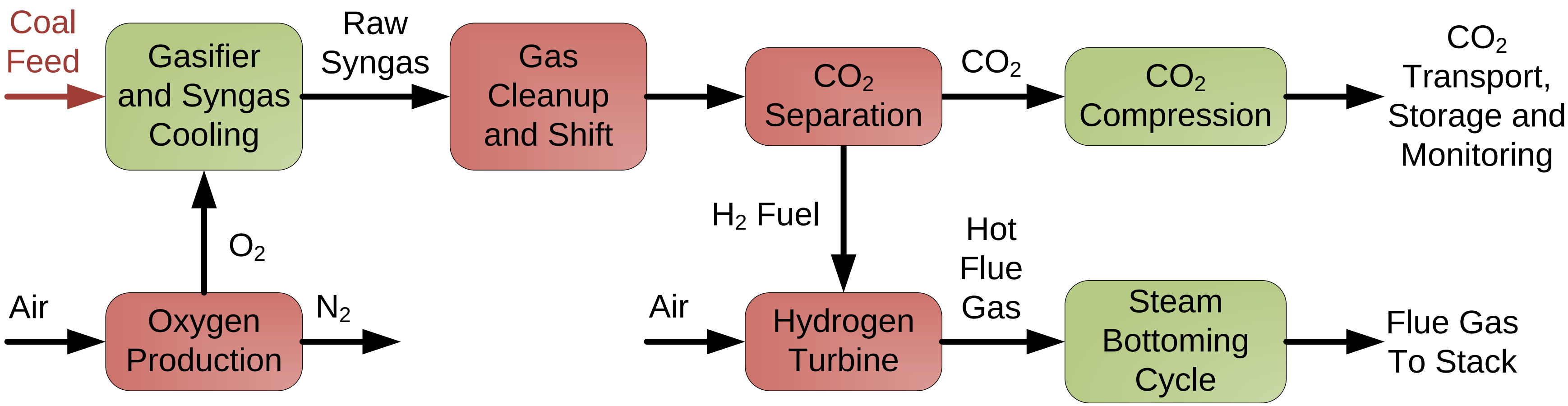
Anticipated January 2012

2ND GEN IGCC WITH CARBON CAPTURE

Systems Analyses for Advanced IGCC

- **Objectives:**
  - Evaluate improved performance and cost resulting from DOE-funded R&D
  - Identify enabling technologies within the portfolio
  - Show relative contribution of different R&D efforts
  - Identify/highlight gaps for low rank coal R&D pathway
- **Approach:**
  - Begin with established cost and performance of conventional IGCC
    - CoP E-Gas selected as reference plant
  - Substitute conventional technologies with advanced technologies in a cumulative fashion assuming successful R&D
  - Evaluate cost and performance in a manner consistent with baseline studies

Advanced Technology Progression



	Technology Progression				
Gas Cleanup	Physical Solvent		→		Warm Gas Cleanup (WGCU)
CO_2 Separation	Physical Solvent		→		H_2 Membrane
Gas Turbine	Advanced F-Class		→		Advanced Hydrogen Turbine
Oxygen Production	Cryogenic Air Separation		→		Ion Transport Membrane (ITM)
Availability	80%	→	85%	→	90%

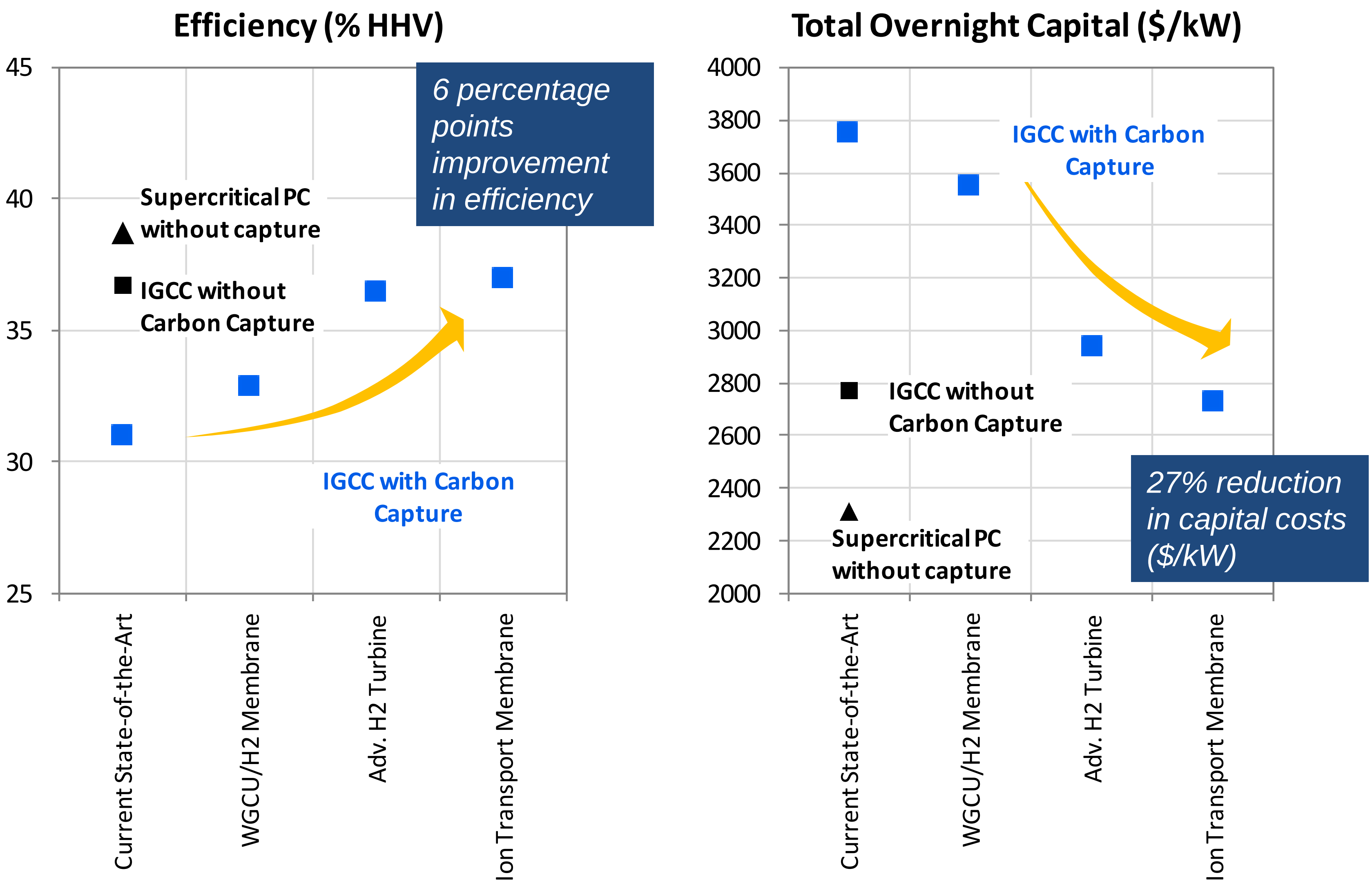
Advanced Technologies for IGCC

- **Warm gas cleanup (WGCU)/desulfurization using transport desulfurizer**
- **High temperature hydrogen transport membrane for CO2 separation**
  - 100% hydrogen selectivity; separation at elevated pressure and temperature
  - Nitrogen diluent provides sweep gas to hydrogen membrane
  - Reduces CO_2 compression load and eliminates solvent separation auxiliary requirements
  - Warm gas cleanup and hydrogen membrane pairing key
- **Advanced hydrogen turbine**
  - Higher firing temperature and design for H2-rich fuels improve turbine performance
  - Allows air integration
  - Steam cycle temperature increases improving steam cycle efficiency
  - Increase in power rating (250 MW v 370 MW) economy of scale benefit
- **ITM for oxygen production**
  - ASU is 15% of capital costs, consumes 10-15% of power
  - Technology pairing considerations
    - Integration with advanced turbine
    - Hydrogen membrane requires minimal oxygen content in vitiated air for use as sweep gas
- **Availability improvements**
  - Advanced materials, instrumentation and controls
  - Demonstration and operating experience
  - Need for high availability of 2nd Gen technologies

Key Performance and Cost Assumptions

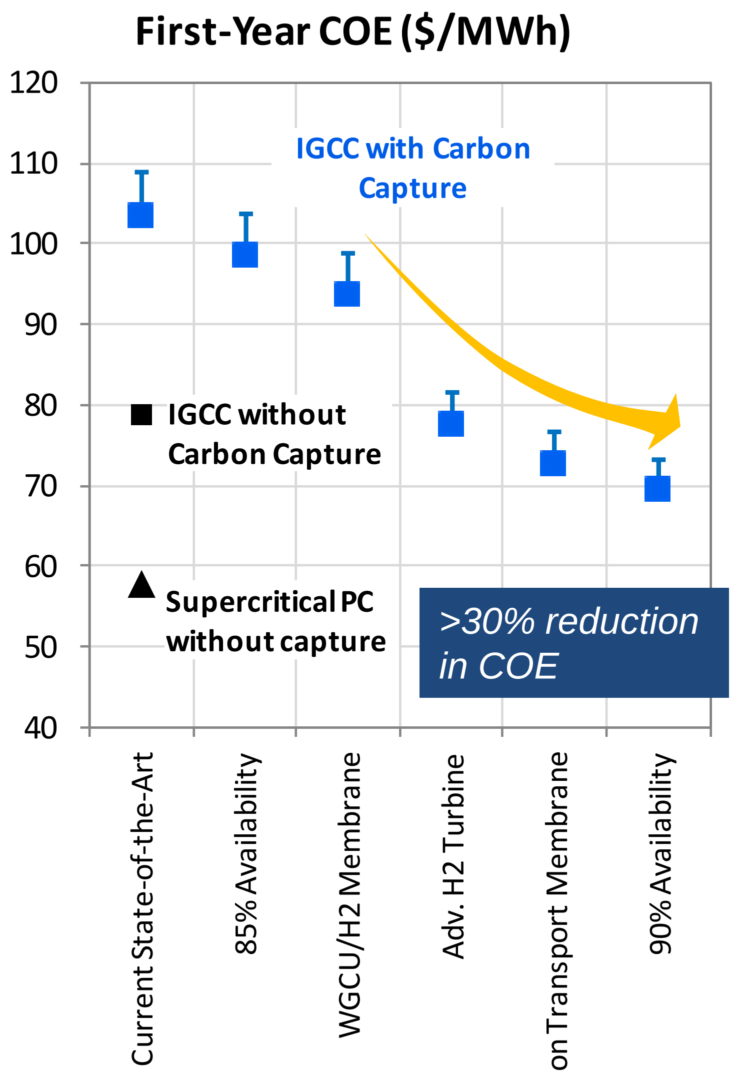
- **Advanced hydrogen turbine**
  - Business-sensitive nature of technology developer data impact modeling capability
  - Costs scaled to power rating assuming no additional premium due to higher firing temperature, improved materials, etc.
  - Plant economics highly sensitive to turbine power rating (advanced turbine results in 900 MW plant)
- **Warm gas cleanup and hydrogen membrane**
  - Performance is mix of demonstration data and targets
  - Cost results sensitive to projected costs that are significantly lower than 2-stage Selexol
- **Ion Transport Membrane**
  - Targets nominally 1/3 lower cost than cryogenic ASU
- **Availability**
  - Steps in pathway not tied to specific R&D
  - Increase assumed to occur without significant change in total plant cost or efficiency
  - Capacity factor is assumed to equal availability

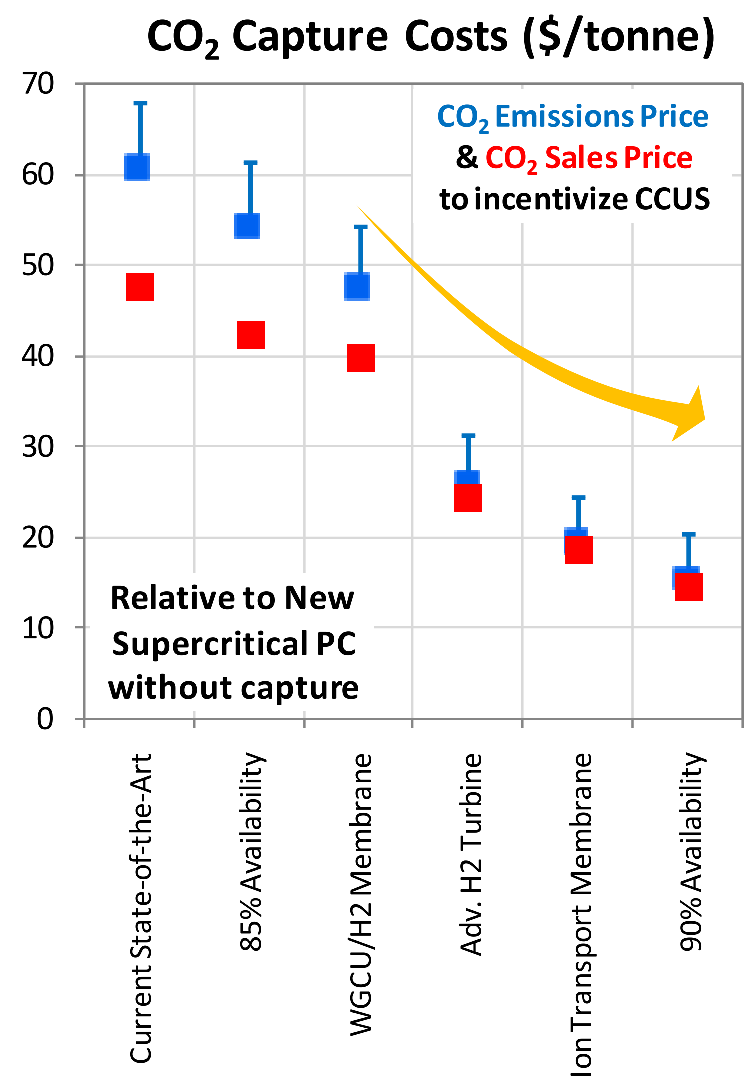
2nd Gen IGCC: Efficiency and Plant Cost

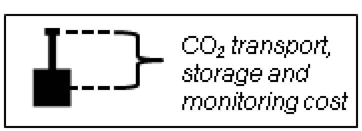


PRELIMINARY RESULTS – SUBJECT TO CHANGE

2nd Gen IGCC: COE and CO_2 Capture Costs







PRELIMINARY RESULTS – SUBJECT TO CHANGE

Lowest Cost Power Generation Options

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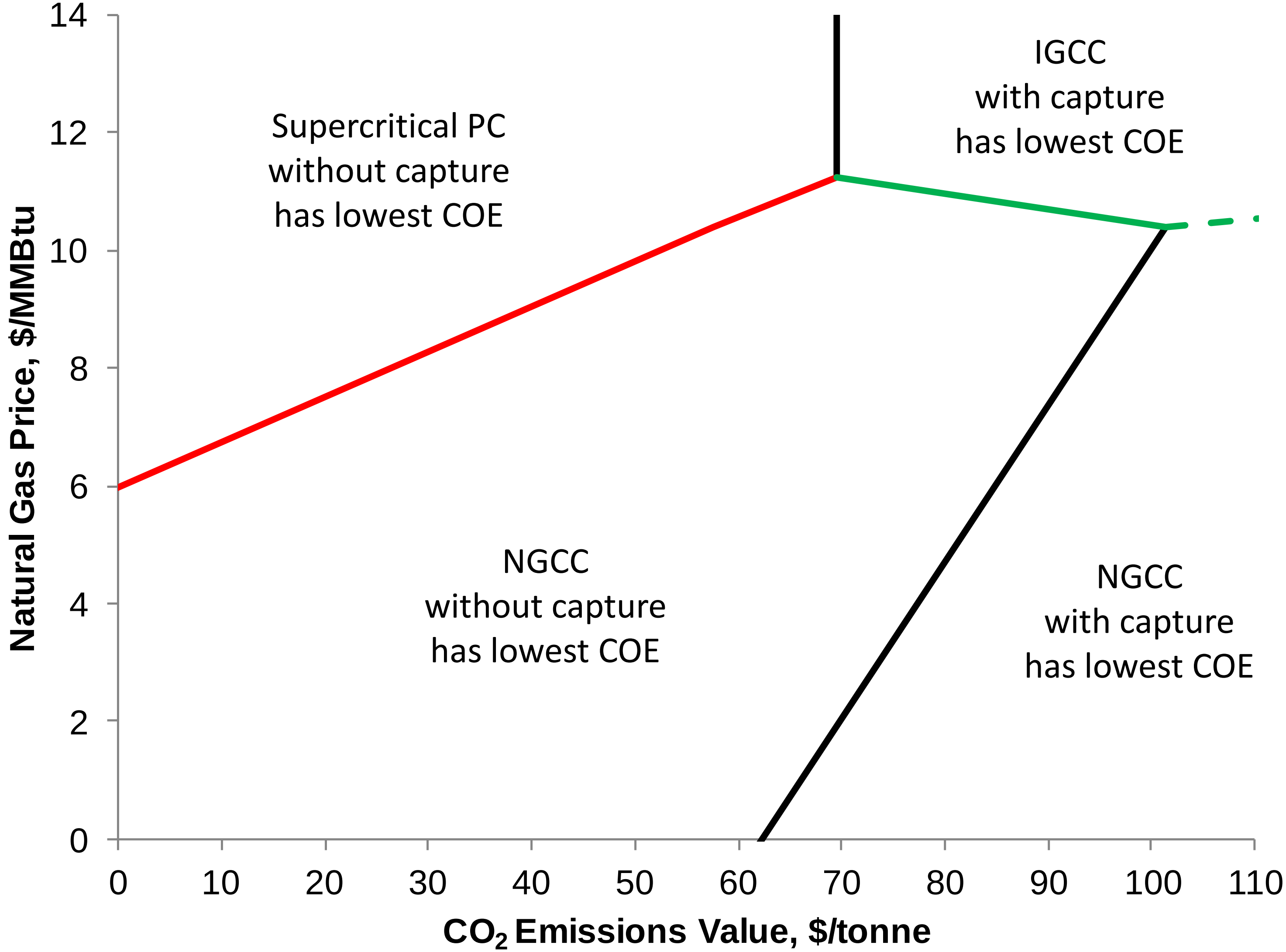

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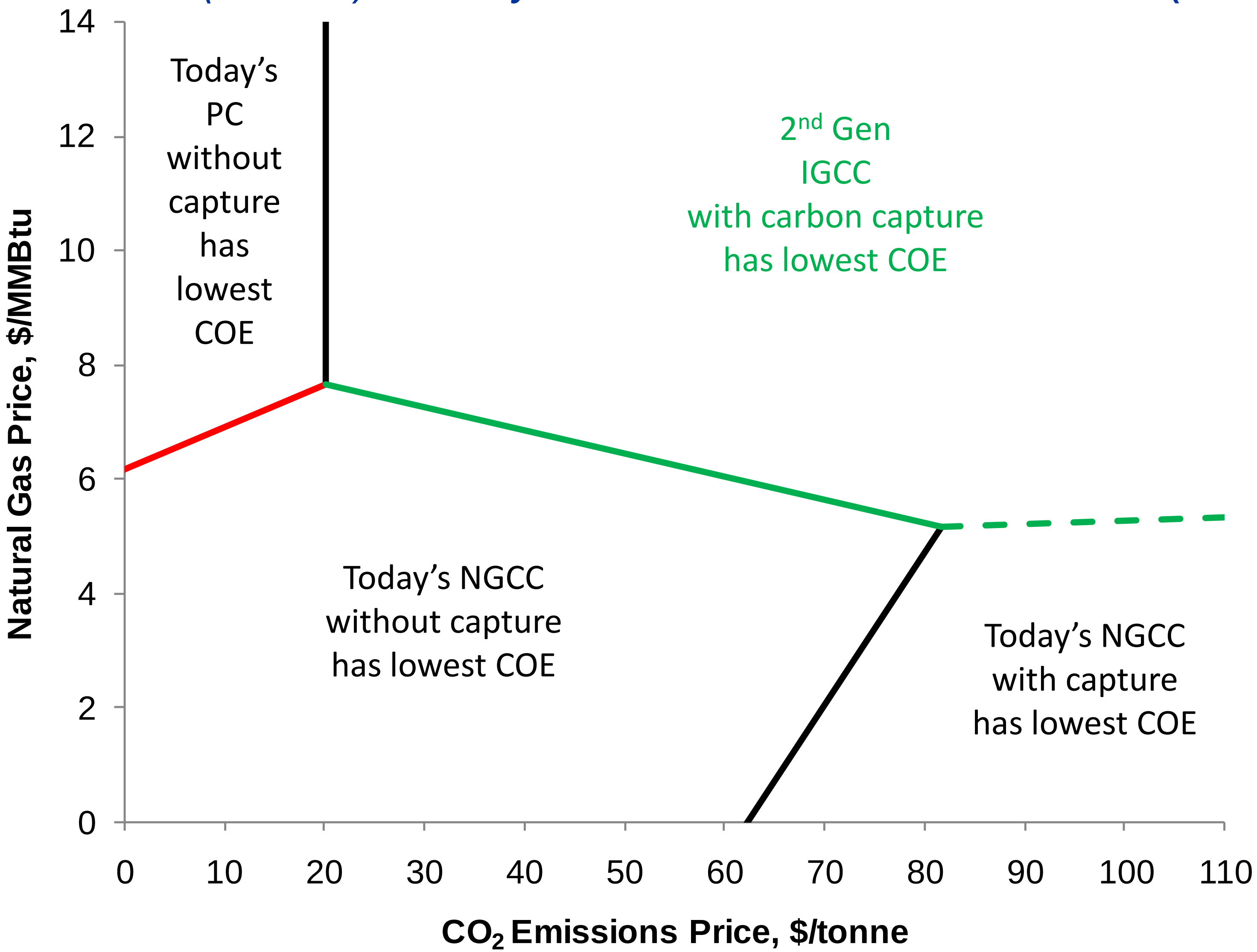
Lowest Cost Power Generation Options

Western (3400 ft): Today's NGCC versus 2nd Gen IGCC (PRB)



Assumes capacity factor = availability (i.e. all plants including NGCC are base load).

Findings of Study and Gaps

- **Current DOE portfolio provides 6 points efficiency, >30% reduction in COE relative to today's IGCC with CCS**
- **High pressure gasification may be needed to enable advanced technologies in current R&D portfolio**
  - Managing WGCU pressure drop, hydrogen membrane driving force, meeting fuel gas pressure needs for advanced hydrogen turbine
- **Evaluation of alternatives to slurry-fed gasification for 2nd Gen IGCC recommended**

LOW RANK IGCC PATHWAY NEXT STEPS

IGCC Pathway Next Steps

R&D Gaps for Low Rank Pathway

- **High pressure gasification for enabling advanced technologies in current DOE portfolio**
- **Addressing high inherent moisture, high alkali metals, & high oxygen content for low rank coals**
- **Alternate pathways for integration with advanced pre-combustion capture**
- **Capitalization on high reactivity and low sulfur for low rank coals**
- **Step changes required to meet availability targets while minimizing costs (for both bituminous and low rank coal IGCC)**

IGCC Pathway Next Steps

Six New Projects to Advance IGCC Technology

Objective: Produce results that reduce the COE, while maintaining or improving plant efficiency. Address key challenges to IGCC commercialization with CCS.

Topic Areas

1. Novel Gasification Technology Exploiting the Availability of (Pressurized) CO_2 Within the Gasification Plant
2. Scoping Studies for Novel Low Rank Coal IGCC Technologies
3. Gasification Plant Availability and Cost Improvements

Topic Area	Proposals Accepted (announced 9/9/11)
1. CO_2 Reuse in IGCC	1
2. Low Rank Coal IGCC	3
3. Gasification Availability	2

Low Rank IGCC Pathway Next Steps

Advanced IGCC New Projects/Scoping Studies

- **General Electric (GE) Company: Advanced dry feed system for low rank coal in IGCC**
  - Objective: Evaluate and demonstrate the benefits of novel dry-feed technologies to feed low rank coal into commercial IGCC systems
  - Team members: GE, Eastman Chemical Company

- **Electric Power Research Institute, Inc. (EPRI): Liquid CO_2-coal slurries**
  - Objective: Study potential advantages of CO2 slurries of low-rank coal for IGCC
  - Team members: EPRI, Dooher Institute of Physics and Energy, WorleyParsons Group, Columbia University, ATS Rheosystems/REOLOGICA

Low Rank IGCC Pathway Next Steps

Advanced IGCC New Projects/Scoping Studies

- **TDA Research, Inc.: Advanced CO_2 Capture Technology for Low-Rank Coal IGCC Systems**
  - Objective: Demonstrate the technical and economic viability of a new IGCC power plant designed to efficiency process low-rank coals using an integrated CO_2 scrubber/water gas shift catalyst
  - Team members: TDA Research, Inc., University of California at Irvine, Southern Company, ConocoPhillips

- **Air Products and Chemicals, Inc. (APCI): Advanced acid gas separation technology for the utilization of low rank coals**
  - Objective Determine the ability of adsorbents for a Sour PSA system in handling impurities resulting from the gasification of low rank coals, while separating sulfur containing species, CO_2 and other impurities
  - Team members: APCI, Energy and Environmental Research Center - University of North Dakota

Low Rank IGCC Pathway Next Steps
NETL Assessments

- **Conduct parallel scoping studies for new projects**
  - Evaluate potential to reduce COE
  - Consider for future inclusion in Low Rank Coal Pathway analyses
- **Expand "Baseline Study" portfolio**
  - TRIG: Add air-blown and lignite coal gasification
  - Evaluate low rank coals for midwest conditions
    - Coal transport cost and elevation trade-offs
- **Quantify and qualify drivers for availability**
  - Conventional IGCC
  - 2nd Gen IGCC systems
  - Gap analysis

Key Take-Aways

- **State-of-the-Art low rank coal IGCC**
  - On par with bituminous coal IGCC
  - Competitive with PC for carbon capture
  - Faces challenges in U.S. market
- **2nd Gen low rank coal IGCC**
  - 6 percentage point efficiency, 30% COE improvement
  - Significantly improves competitiveness of IGCC CCUS
- **Low rank coal IGCC pathway next steps**
  - New DOE projects
  - New analyses of state-of-the-art IGCC systems
  - Evaluate the availability “gap”

Contributors

- **NETL**
  - Jenny Tennant, Gasification Technology Manager
  - Richard Dennis, Turbines Technology Manager
  - James Black, lead for Baseline Studies

- **Noblis, Inc.**
  - Advanced IGCC modeling & analysis
  - John Plunkett, David Gray, Charles White, Sal Salerno

- **Booz Allen Hamilton**
  - Conventional IGCC modeling & analysis
  - Vincent Chou, Mark Woods

Additional information available at:
http://www.netl.doe.gov/energy-analyses
http://www.netl.doe.gov/technologies/coalpower/gasification